STRUCTURE OF THE METAMORPHOSED GABBRO COMPLEX AT BALTIMORE, MARYLAND

A dissertation submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy

BY

CHARLES J. COHEN

1935

THE JOHNS HOPKINS PRESS

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STRUCTURE OF THE METAMORPHOSED GABBRO COMPLEX AT BALTIMORE, MARYLAND

INTRODUCTION

The subject of this investigation is a complex of basic and ultrabasic rocks which are metamorphosed in various degrees. The area lies in the Piedmont of Maryland west and northwest and in part within the city limits of Baltimore and occupies approximately 50 square miles. The rocks were made famous by the petrographic studies of G. H. Williams (104–110) fifty years ago. He was concerned primarily with the alteration processes. His report published in 1886 (108) has made the area a classic illustration of uralitization.

The present study was undertaken upon the suggestion of Dr. Ernst Cloos in the hope of discovering the mode of emplacement of the rocks. It was thought that the intense and conspicuous foliations of the rocks could be a primary flow structure. The investigation demonstrated, however, that the principal structure may not be primary, but a result of partially intense metamorphism, and that the primary structures are transected and have in part been obliterated by secondary structures. These structures prove of great interest.

The descriptive part of this report deals with the geologic setting, the contact phenomena, and the structures of the gabbro complex. The internal structures are outlined in two parts: (1) petrographic and (2) structural, supplementing the descriptive part of the structure and the history of the complex.*

GEOLOGIC SETTING

The Baltimore gabbro occurs in a peneplained area. The investigation was somewhat hampered by lack of good exposures. The best ones are in

* Ed. Note: At the end of this report are supplementary notes by the editor. Since the investigations have been continued by other workers it has become necessary to incorporate newer findings and to outline the history of the region in the light of new results. The author, who has been in Rhodesia for several years, would most likely have expanded his views somewhat if he had had the new results available. The great distance and cumbersome correspondence between Baltimore and Rhodesia made a discussion impossible. The editor has therefore added his comments for which the author is not responsible.

the valleys of three southeast draining streams entrenched in the old peneplain: Jones Falls, Gwynns Falls, and the Patapsco River.

The details of the geologic setting are described in other papers of this volume (pt. III) and brief remarks here will suffice. The gabbro body forms a bulge in a belt of basic rocks extending northeast from Virginia through Maryland and into Pennsylvania and Delaware. The country rocks are the Baltimore gneiss , the Relay quartz diorite and the Glenarm Series. The gabbro bulge occupies a structural basin in the Glenarm Series and the Baltimore gneiss. The outer margin of the basin closely adjoins the gabbro and is marked by four major domes of Baltimore gneiss overturned to the south and southeast. The gabbro is intruded by several granitic intrusions.

PETROGRAPHY

THE PRINCIPAL ROCK TYPES

G. H. Williams (108) in his well known paper on the alteration processes in the Baltimore gabbro and in other papers has given a very thorough petrographic description of most of the rock types. His collections of rocks and thin sections are still available.

The rocks may be divided into two principal types: basic and ultrabasic. Ultrabasic rocks underlie 15 per cent of the area. In the following discussion the rock names will be defined as employed in this paper. Principally four rock types are distinguished, two igneous and two metamorphic ones.

1. *Pyroxene gabbro* refers to pyroxene, basic plagioclase rocks. The pyroxene gabbro consists of roughly equal amounts of feldspar and pyroxene. The feldspar is Ab_{15} An_{85}—a bytownite. The pyroxene is both orthorhombic and monoclinic. Accessories are magnetite, apatite, rarely olivine, and indeterminate inclusions in the minerals. The pyroxene-feldspar ratio is rather high locally and the pyroxene gabbro grades into pyroxenite. The grain size varies between one millimeter and three millimeters, except for coarse gabbro pegmatite. The minerals are hypidiomorphic equant. The pyroxene generally has rounded edges while the feldspar is more often indented. The texture is practically always massive. In sharp contrast with the gabbro, fresh specimens show cleavage faces of feldspar.

2. *Hornblende gabbro* is likewise a pyroxene, basic plagioclase rock, but containing brown hornblende in addition to the gabbro minerals. The type was recognized by Chester (24) in Delaware. The refractive indices of the hornblende are not quite high enough to warrant the term basaltic hornblende. The mineral occurs in compact grains with sharp boundaries

against pyroxene and feldspar. The latter minerals are as fresh as in pyroxene gabbro and the pyroxenes generally have the same hypidiomorphic form in the rounded edges. The hornblende boundaries in contrast are generally concave. Hornblende may poikilitically enclose rounded pyroxene and feldspar grains. It is also found in cracks in pyroxene. It is clearly younger than pyroxene but is older than uralitization. It may be regarded as a pyrogenic reaction mineral. The rock is further characterized by a foliation in contrast with the massive pyroxene gabbro. Slightly tabular pyroxene, feldspar tabular parallel to 010, and elongated irregular shaped brown hornblende contribute to the foliation. The presence of a primary foliation in the younger magmatic phase agrees with the relation noted by Balk (8) in the structure of the Peekskill norite body.

3. The term *metagabbro* refers to uralitized gabbro and consists essentially of pyroxene, uralite, and basic plagioclase. As shown by Williams, a green hornblende, basic plagioclase rock is the end member of the series of uralitized rocks. Uralite is an aggregate of microscopic fibers of amphibole derived by alteration from pyroxene (107, p. 52). All transitional types between a pyroxene rock and green hornblende-bearing rock are present. All uralitized gabbros with pyroxene relicts are massive, except for a few specimens derived from foliated hornblende gabbro. Mineral alignment of hornblende needles does not necessarily accompany uralitization.

4. The term *amphibolite* is used to denote a rock composed essentially of basic plagioclase and green hornblende, the latter aligned in varying degrees. The hornblendes are elongated prisms roughly bounded by cleavage planes and have ragged edges. The texture is therefore crystalloblastic. Feldspar too has rarely been noted aligned. Epidote is an important constituent.

Ultrabasic rocks. A wide range of ultrabasic rocks occur and these likewise together with the alteration processes, have been studied by Williams. The group includes varieties of periodotite, pyroxenite, serpentine, talc schist, and amphibole schist.

The usage of *peridotite* is conventional and unambiguous. The pyroxenites consist essentially of orthorhombic and aluminum-bearing monoclinic pyroxenes. They are generally medium grained and have a massive texture. The individual crystals are hypidiomorphic, equant. In the more calcic pyroxenites, particularly, the rock approaches a saccaroidal character due to the ease with which the individual pyroxene grains break out.

The rocks are unusual in that olivine is interstitial to large pyroxene crystals, contrary to the general rule. It may be noted that incongruent partial melting of a pyroxene rock followed by filter pressing is a process

which can produce this unusual feature. Only the edges of the pyroxene grains would fuse and olivine alone would be left in the interstices.

The term *pyroxenite* is used in the conventional sense.

The ultrabasics which have been shown to be derived from pyroxenites and peridotites are far more abundant than the primary rocks. They comprise serpentine, amphibolite, chlorite, and talc schists and soapstones. Of these amphibole schists are the most common and serpentines comprise most of the remaining rocks.

The term *serpentine* is used conventionally. Serpentine and not hornblende has been derived from pyroxene in cases where the original proportion of olivine was large. An unusual serpentine (Plate XXXVI, fig. 2) adjoining some large boulders of quartz was found near a small stream one mile north of Union Dam. It consists of slender fibrous sheaves up to one inch long of chrysotile embedded in a groundmass of antigorite with a "feathery" texture.

Talc schists occur both massive (soapstones) and schistose, indicating perhaps hydrothermal *and* dynamic alteration.

Amphibole schist is used to denote a metamorphic ultrabasic rock consisting essentially of amphibole. It is in many cases a monomineralic rock and the amphibole a member of the tremolite-pargasite series. Less commonly the amphibole schists are massive.

CONTACT AND LOCAL ALTERATIONS

The principal mineralogic contact effect lies in the Wissahickon schist. *Garnets* are abundantly developed and at Sudbrook Park well formed equant garnets reach a size of one and one-half inches in diameter. Garnets are found also in the gabbro close to the schists at Hollofield, south of Rockland, and at Sudbrook Park. *Epidote* is also abundant in the amphibolites of the mixed gabbroic-Wissahickon rocks south of Bare Hills as to suggest it as an endomorphic contact mineral. It occurs in streaks, knobs, and nodules two feet in diameter.

The amphobolites in the southeastern portion of the area near the intrusion of the Relay quartz diorite have been extensively *saussuritized*. The rock weathers rapidly and is frequently rusty looking and fractured. The fractures are filled with thin sheets of felsic material. Saussuritization has affected only the feldspar but the hornblende folia are as in other amphibolites. This alteration indicates a low grade dynamic metamorphism subsequent to the formation of the amphibolite, and it may be attributed to the intrusion of the quartz diorite.

Chloritization of amphibolite is common in a small area one and one-half miles southeast of Hollofield. It is confined to irregular zones extend-

ing up to a few inches from a strong set of cross joints. The alteration is a replacement of hornblende by chlorite. It is remarkable in that feldspar is unaffected, an immunity which must be attributed to low temperature.

Minor *assimilation and solution effects* have been noted at the contacts with felsic veins. Examples are hornblende needles and epidote in Relay quartz diorite aplite, gabbro ghosts in Port Deposit granite aplites, and relative enrichment in mafic constituents of the gabbroic rocks at the border of felsic veins, as by selective solution.

"*Honeycomb ironstone*" is a term which has been used to denote chunks of a cellular iron-stained silicious rock generally found as float. The septa are of chalcedony, terminated quartz, interlocking quartz, and hematite—material evidently deposited from a colloidal suspension. The rock, as is generally recognized is a concomitant of the weathering of serpentines. That serpentine occupied the cells is shown by a single specimen, found in Cedar Branch, some cells of which are still filled by serpentine (Plate XXXVII Fig. 1b). The occurrences at Baltimore indicate that the cellular rock does not form in country undergoing rapid erosion. It is abundant on the old peneplain surface, near serpentines, and rare in dissected regions. A process leading to a similar product may, however, be seen in rocks so recently exposed as in railroad cuts. The weathered surface in such cases is cut by numerous such septa resulting in very much smaller cells and these are still filled with serpentine. It is suggested that when weathering extends deep beneath the rock surface, as during long exposures on a peneplain, the honeycomb ironstone with its relatively coarse dimensions forms through the same process.

DISTRIBUTION AND RELATIONS OF THE ROCKS

Distribution in the Main Body

The basic rocks are approximately five times as abundant as the ultrabasic ones. Of the basic rocks probably nine-tenths are amphibolites. Metagrabbro and gabbro are roughly equally abundant and hornblende gabbro is known from just four occurrences. Of the ultrabasic rocks the most abundant are likewise the metamorphic ones, principally serpentine and amphibole schist.

The distribution of the types is unsystematic. In particular the marginal distribution of ultrabasic rocks, typical of undeformed gabbro lopoliths, is lacking. It is true that talc, amphibole, and chlorite schists are common at the contacts, for example the western contact, that at Sudbrook Park, those of the Rockland tongue. These, however, are very small bodies of ultrabasic rocks. Many of the large ones are near the margin, but many are also away from it. In the center of the complex

there are, for example along Gwynns Falls, feldspathic and magnetic serpentines, northwest of Forest Park Avenue, and amphibole schists to the southeast. When closely studied it seems that ultrabasics occur within a mile of every point within the complex.

A minor exception to the random distribution is the common presence of talc or chlorite schist at the margin of the less hydrated ultrabasic rocks.

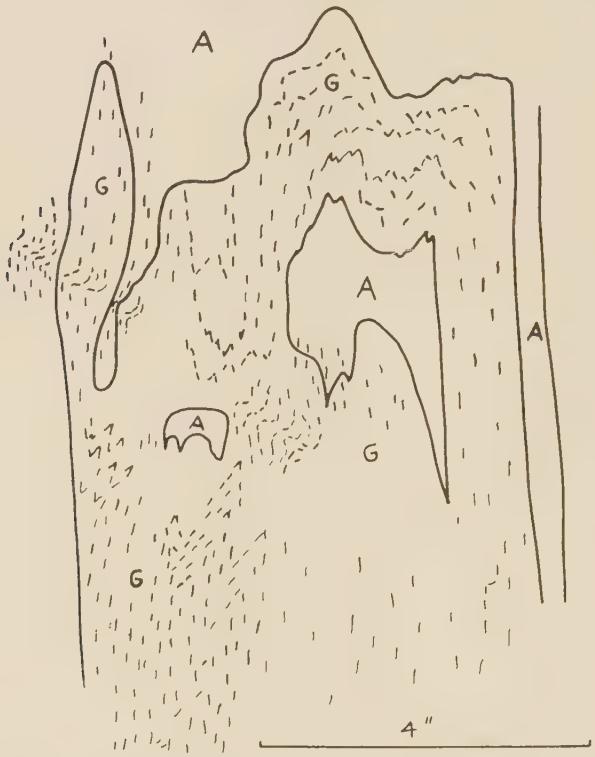

FIG. 28.—Contact of amphibolite (G) with amphobolite schist (A). Forest Park Avenue at Hillsdale.

In particular, marginal talc schist completely surrounds the Bare Hills serpentine.

True gabbro is most common in the northern and northwestern portion of the complex. It is, however, found principally on the peneplain and as boulders. Its relative abundance may therefore be due to concentration during peneplanation because it is extremely resistant to weathering.

Regarding distribution it can further only be added that there are random areas of mixed unaltered types and areas of mixed metamorphic types and that each igneous type is associated with its metamorphic equivalent.

FORM OF OCCURRENCE OF ULTRABASIC ROCKS

The outlines of the larger masses of ultrabasic rocks generally can not be mapped precisely for want of exposures. The Bare Hills serpentine is exceptional because of the thin soil. It is readily delimited and has an oval outline. Of the smaller masses from an inch to 20 feet across, many are tabular and all have sharp contacts with the basic rocks. Others have very irregular boundaries probably in part due to later deformations.

Williams and all subsequent writers have referred to the ultrabasic bodies as dikes. The only possible suggestion of a dike is the tabular shape of the smaller bodies and the invariably sharp contacts. The data themselves do not suggest dikes because many basic intrusions are now known with bands of ultrabasics as integral parts of the bodies (e.g. the Bushveld complex). For such an occurrence diking is an untenable hypothesis and the idea of differentiation by crystallization, which leads to the early segregation of olivine-bearing and pyroxenite rocks, is hardly challenged. A difficulty of the dike hypothesis is seen in the Baltimore area itself where basic and ultrabasic rocks are associated in and confined to a narrow tongue extending 2 miles from the main body south of Rockland. The ultrabasic rocks of this tongue are not dikes. A segregation hypothesis seems more plausible. It may be added that gabbroic veins, of uncertain provenance, are locally found cutting amphibole schist.

AMPHIBOLITES OF THE BALTIMORE GNEISS AREA

The Baltimore gneiss dome southeast of the main gabbro mass contains considerable quantities of amphibolite. Various lines of evidence lead to conflicting estimates of their age. They might have been formed before or after the deposition of the Glenarm Series. On the geologic map of 1892 Williams (105) classed the amphibolites of the Baltimore gneiss with those of the main gabbro complex. Jonas and Knopf followed this plan and in their 1929 report did not refer to the problem (64).

The gneiss dome at Baltimore is bounded concordantly on the northwest and west by a mica schist considered part of the Setters formation. This schist belt is only a few hundred feet wide at Gwynns Falls but gradually widens to the northeast. At Gwynns Falls the gabbro complex is separated from the Baltimore gneiss only by a thin sheet-like body of Relay quartz diorite. On the north the dome is bounded by amphibolites, ultrabasic rocks, and metagabbro. Mica gneiss was reported in a Maryland Geological Survey well record as far north as Canterbury Road and Highfield north of University Parkway.

The phase of the Baltimore gneiss quarried in Gwynns Falls and Jones Falls is a banded gneiss in which the bands have great persistence. The

strike is consistently N 40°–70°E, 35°N, southwest of Jones Falls. On Stony Run south of University Parkway it has veered to N 10°W, 90°. No ultrabasic rocks have been found by the writer in this area though to the northeast, in Harford County, they are associated with the Baltimore gneiss. The basic rocks are amphibolites none of which quite satisfy the description of those of the gabbro complex. They differ in (1) the frequent presence of important quantities of biotite and (2) a much more intense planar foliation accompanied by only a faint linear foliation. The habit of the hornblende is often tabular parallel to a cleavage rather than the linear arrangement which is common in amphibolites.

At Gwynns Falls where the amphibolites are closest to the gabbro complex they are not at all altered like the rocks of the complex in contact with the Relay quartz diorite. Moreover they are isoclinally folded, also unlike the rocks of the gabbro complex (Plate III Fig. 1).

The distribution of the amphibolites in the Baltimore gneiss is not systematic. They are particularly dominant over the Baltimore gneiss at the contact with the mica schist both on Gwynns Falls and Stony Run, and are somewhat less important on Jones Falls at this contact. Though the exposures in the railroad cuts are good, basic rocks are nowhere found within the belt of mica schist. It is highly probable that the basic rocks have been interbanded with the Baltimore gneiss before the mica schist came into contact with the gneiss.

Metagabbro is not present in the Baltimore gneiss area though but slightly schistose amphibolite is well exposed in the center of a large mass of amphibolite 1000 feet across outcropping on the Pennsylvania Railroad just east of Union Station. It contains swirling bands (bed of Jones Falls before entering Fallsway aqueduct) typical of gabbros and suggestive of the igneous origin of the amphibolites.

Aside from such large bodies the amphibolites are in persistent sheets and thicker masses conformable in the Baltimore gneiss. The sheets vary in thickness from a millimeter up to 100 feet. The arguments favoring the pre-Glenarm age of at least some of the Baltimore gneiss are:

1. Petrographic differences: a. Frequent presence of biotite, b. Different habit of hornblende.

2. Where occurring close together the gabbro is altered and intensely fractured while the Baltimore gneiss amphibolites are folded and unfractured.

3. Amphibolites are not present in the Glenarm mica schist adjoining the amphibolite-bearing Baltimore gneiss.

The problem is not peculiar to this region. It has been encountered and left unsettled in the eastern United States by the workers in the gneisses of western North Carolina and of Virginia, by the authors of the Phila-

delphia Folio, Jonas and Knopf in the Quarryville quadrangle, the students of the oldest gneisses in southeastern New York, by Alling, Balk, Cushing, Martin, Newland, and Smyth in the Adirondacks, and other localities in the Canadian Shield.

DIRECTED STRUCTURES IN THE GABBRO MASS

Banding

A striking feature of all the basic rock types is banding (Plate XXXIX, Fig. 1). It consists of an alteration of tabular shaped bodies of rock which have different relative amounts of the constituent minerals with or without a variation in grain size. The contacts often have knife-edge sharpness. The thickness of a band is quite variable, ranging from a quarter of an inch up to 2 feet. A determination of the lateral extent of a band depends on the presence of large continuous exposures. One hundred feet is the maximum found (Hillsdale Quarry), but there is no reason to believe that they may not be very much longer. In general very acid bands are more persistent than very basic ones. Bands have been found to terminate by wedging out and by lateral variation in composition until they grade into the adjacent bands.

All the bands of a group usually have the same mineral facies. That is, a group may be pyroxene gabbro; it may be metagabbro; or it may be amphibolite. Exceptionally, foliated amphibolite and massive metagabbro may be interbanded in which case the amphibolite is more melanocratic. This is significant, showing the greater ease with which the more basic and ultrabasic rocks react to dynamic metamorphism. Bands crossing one another have not been found.

Schistosity in Amphibolites

According to the usage here adopted amphibolites are by definition schistose. The schistosity is due to subparallel elongated or flattened folia, no longer than the average feldspar, consisting of more or less aligned hornblende grains. The number of grains in a patch varies from perhaps 1000 down to one and the shape of the hornblende is most elongated in the most compact folia. The hornblende crystals have the shape of cleavage prisms with jagged terminations. A linear schistosity appears when the prism axes alone are subparallel, a planar schistosity when the axis lie at random but within a plane. In the case of planar schistosity the *b* (crystal) axis as well as the *c* (prismatic) axis tends to lie in the plane. This was found in oriented thin sections from localities where the structures were quite different (a. Herring Run, and b. Union Dam on the

Patapsco). Generally feldspar alignment is not present or can not be recognized.

CROSS JOINTS IN AMPHIBOLITE

A set of joints transects the linear schistosity of the amphibolites approximately at an angle of 90 degrees. These cross joints are smooth, plane, subparallel, and persistent in their direction. Their frequency, parallelism, and persistence depends on the intensity of linear schistosity of the amphibolites.

No other set of joints except a weak fracture cleavage (Plate XL, Fig. 2) is sufficiently developed to be of value in a structural analysis.

OTHER DIRECTED ELEMENTS

Foliation in gabbro.—Pyroxene gabbro has a massive texture. However, hornblende gabbro is foliated and its foliation is primary. Because of its rarity it is not important as a structure element.

Fracture cleavage in serpentine.—The serpentines are massive in texture and flow cleavage has not been found. A fracture cleavage has been found but it is not common. It consists of small, subparallel fractures from a fraction of an inch to several inches and, as an average, about one-quarter of an inch apart but with zones of closer spacing. Feldspars are dimensionally aligned in a serpentine outcropping near Gwynns Falls and Forest Park Avenue. Joints, rendered conspicuous by the familiar form of weathering of serpentines, show random orientation and are of little structural significance.

Schistosity in amphibolite schists.—The amphibole schists are frequently massive and schistosity is ordinarily much less developed than in the amphibolites. The structure consists primarily in a linear mineral arrangement. Some very fine grained amphibole schists with a silky luster show an intense planar cleavage.

Refracted joints.—An interesting feature of jointing, shown at only one locality, is the refraction of steep joints cutting flat-banded amphibolite (Plate XXXVIII, Fig. 2). The joints are vertical in the less basic bands and less steep in the more basic bands. Elsewhere all joints cut the banding without refraction.

Schistose zones.—Zones from one to six inches thick of intensely schistose amphibolite have been noted. The zones (Plate XXXIX, Fig. 2) are not rectilinear but bulge, narrow, curve, and even fork. Generally banding is displaced slightly and drags on planes of displacement have been observed. Less intensely schistose amphibolite zones transect massive gabbros. The age and significance of these structures has not been posi-

tively established. Some have an orientation and linear schistosity parallel to the linear structure in the amphibolites and have probably been formed at the same time.

Flexures of schistosity.—The attitude of schistosity is generally uniform on a small scale. However, in places it is flexed. These flexures consist in small zones perhaps an inch wide and a foot long. A relatively intense schistosity is oriented parallel to the plane of the disturbance. The regional orientation of these flexures is irregular.

Remarkably sharp and minute folding of linear schistosity in amphibolite was noted in a boulder. The two limbs of a fold are equally schistose and rectilinear. The crest is sharply pointed. Limbs wedge out by the tapering of the equally rectilinear axial planes (Plate XL, Fig. 1). A similar type of folding of planar schistosity was found on a somewhat larger scale in amphibolite north of Oella.

Quartz veins.—Quartz veins are numerous. Usually they consist only of quartz. Schistose and flexed zones are generally followed by these veins. They frequently parallel the schistosity and north of Oella a well developed set of veins paralleled the linear schistosity, the veins themselves being cylinders of irregular section.

DIRECTED STRUCTURES

The Contacts

PRIMARY CONTACTS

The boundaries of the gabbro body against country rock are remarkably conformable and concordant.

The only country rock formation which is definitely cut by the gabbro is the Wissahickon schist of the Glenarm Series. The contact is exposed in the northeast corner of the area near Bare Hills, on the north border at Sudbrook Park, and on the western border on Bens Run at the Patapsco River. Here the boundary is a zone of intertonguing amphibolite and Wissahickon schist (Fig. 29). It is widest approximately 2 miles south of Bare Hills. The planar and linear schistosities in the intrusive is parallel with that in the country rock. The contact and the schistosity are either vertical or dip under the gabbro. The dip is between 40 and 75 degrees south at Bare Hills, vertical at Sudbrook Park, 45 degrees at Bens Run near Dogwood Road, and vertical south of Hollofield. Banding near the contact is not parallel with the contact. For example, at Hollofield banding in the serpentine quarry is flat and the contact is vertical only 200 yards away (Plate XLI).

Two dikes of amphibolite approximately one foot thick have been noted

within a half mile of the boundary in Wissahickon schist. One is south of Hollofield, the other on Bens Run at Ridge Road. Both appear to be greatly deformed; one being bent and the schistosity crinkled, the other bulging, pinching, and fraying. The southeastern contact of the gabbro, against Relay quartz diorite, dips 45 degrees north and northwest and under the gabbro.

FAULT CONTACTS

The northern part of the eastern boundary is a fault. It is marked by a recrystallized breccia (p. 160) which is approximately 100 feet wide at Hollins Station. Similar breccia, perhaps its southern extension, was found within the gabbro on the creek entering Jones Falls from the north-

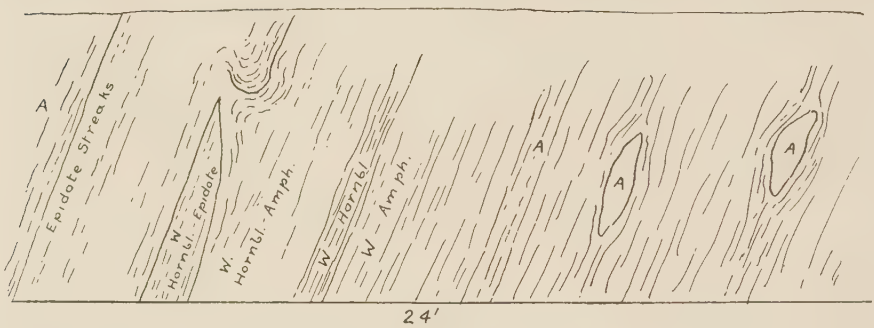

FIG. 29.—Section of mixed Wissahickon schist (W) and amphibolite (A). Pennsylvania Railroad at Mount Washington.

west at Melvale. The cleavage trends in the amphibolite and Wissahickon schist on the one side and the Baltimore gneiss on the other are highly discordant.

CONTACTS WITH YOUNGER INTRUSIVES

Intrusives into the gabbro are the Relay quartz diorite, the Port Deposit granite, the Ellicott City granite, and possibly the gneissic granite at Ilchester. All are conformable, intertonguing with the gabbro rocks. For this reason the age relations are not evident and the following detailed evidence is offered. Offshoots of the Relay quartz diorite intrude the gabbro discordantly. Moreover, the amphibolites in the contact zone have been saussuritized and otherwise altered. The Port Deposit granite cross-cuts the abnormally flat banding in gabbro at one place on Gwynns Falls (See also p. 127). Aplitic and alaskitic dikes with a peripheral distribution about the granite also cut the gabbro. The Ellicott City granite

is younger than the gabbro because associated pegmatites cut the gabbro. The granite itself cuts the amphibolite and its cleavage near Ilchester. Inclusions of banded gabbro in random orientation at Gray and of amphibolite near Oella have been found. The relative age of the Ilchester granite remains undetermined.

RELATIONS OF BANDING TO SCHISTOSITY

As a general rule banding and schistosity are parallel. This rule is confirmed in many exposures and exceptions are too rare to be discovered

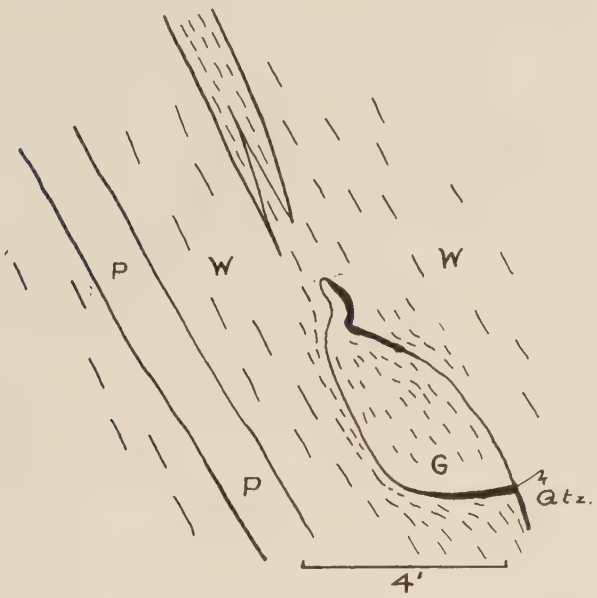

FIG. 30.—Amphibolite (G) in Wissahickon schist (W). Baltimore and Ohio Railroad south of Hollofield; P = pegmatite; Qtz. = quartz veins.

by other than a thorough and methodical search. Exceptions do exist, however. Along the Patapsco River between Hollofield and Union Dam weak but systematic cross-cutting is developed. Here the banding assumes various attitudes, one of which is parallel to the prevailing planar cleavage. Only where banding parallels the cleavage is planar schistosity well developed. If banding is at an angle to the cleavage the latter is very weak or absent. Its orientation is, however, represented by a set of joints or by weak fracture cleavage. Traces of schistosity were megascopically noted paralleling the joints and cross-cutting the bands. In

one instance alignment was masked by the fracture cleavage but was determined in thin section with the help of pleochroism of the hornblendes. The alignment likewise paralleled the fracture cleavage and cut banding. In the one outcrop where banding was actually seen curving into the plane of schistosity, a schistose zone intervened at the beginning of the curve (Fig. 31). A further feature of this Patapsco district is a beautifully developed strong and invariant linear schistosity with complementary cross-joints. The various attitudes of banding are all parallel to the linear structure and the intensity of this schistosity is uniform and independent of the direction of banding.

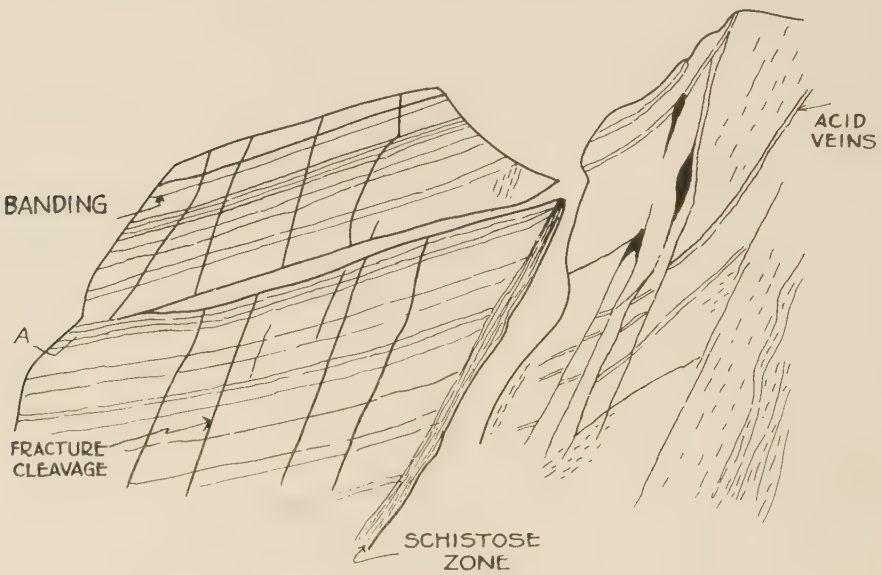

FIG. 31.—Relation of secondary structure to banding, one mile southeast of Hollofield.

Another relation of banding and schistosity is important. Banding may be flat but schistosity is rarely flatter than 20 degrees. It follows from this and the rarity of cross-cutting cleavage that flat banded rocks are generally massive. Flat banded metagabbro may be observed where it grades into amphibolite with steeply dipping linear schistosity on Gwynns Falls 1000 feet southeast of Windsor Mill Road. The bands swirl, steepen, and thin out into cylinders whose axes are parallel to the linear structure. A similar gradation from metagabbros into amphibolite was noted a quarter of a mile southeast of Dogwood Road and Belmont Avenue. In one case of flat banding a plunging linear schistosity was found close to the

contact along the Baltimore and Ohio Railroad one mile south of Hollofield. It is another of the rare exceptions to the rule of parallelism.

THE TREND LINES

The trends of the elements are shown on the accompanying map (Plate XLI). The salient features of their distribution and orientations may be summarized as follows:

The trend is parallel to the contacts at the few exposures along the northern contact; along the entire length of the southeastern contact; and along the contact with the Wissahickon gneiss in the vicinity of Ellicott City, Oella, and north of Hollofield. However, the trend between Hollofield and Oella varies from N 10° W through northeast to east while the contact remains N 10° W approximately. The Ruxton fault cuts the flow elements at an angle of 90 degrees.

The dip when the strike parallels the contact is either vertical or toward the center of the gabbro complex. It dips under the complex at Bare Hills and along the southeastern contact.

The trend within the complex is northeast with a steep dip generally to the northwest.

Secondary planar schistosity embracing amphibole foliation and fracture cleavage is in part followed by acid veins. Everywhere the trend parallels the contact of the complex with the older rocks, even between Hollofield and Oella where the primary foliation is not always parallel to the contact.

Like the primary foliation it is vertical around the western and part of the northern contacts but dips about 50 degrees under the gabbro complex at Bare Hills and along the southeastern contact. Also like the primary foliation it has a northeast trend and a steep dip in the interior of the complex.

The foliation is never flat. It is always as steep as, or steeper than, the primary flow elements.

At the southwest corner of the complex the secondary planar foliation does not close around from the western to the southeastern contact, but it converges and continues on to the southwest.

The structure in the eastern part of the complex is still obscure. The southward continuation of the Ruxton fault (See p. 181) has not been definitely located and the few readings found in the area are not consistent enough to give a reliable picture.

The strike varies considerably. It is quite common to find strikes differing by 45 degrees from the mean in a relatively small area.

South of Bare Hills most bearings are nearly east-west and parallel to the northern contact.

The secondary structures in the country rocks are parallel to the contacts of the complex. Hence the gabbro is conformable.

The strike of the horizontal projection of linear elements is sometimes parallel and sometimes perpendicular to the contact. It is decidedly away from the contact south of Bare Hills and along the southeastern border. It consistently parallels the western contact, especially between Oella and Hollofield.

Within the complex the linear elements plunge in a northerly direction except in the vicinity of Mount Washington. The dip is rarely flatter than 25 degrees. It is generally between 40 and 70 degrees and is vertical near Thistle. It is nearly down the dip of the platy foliation except on the western contact.

The direction of the linear elements is far more consistent than that of the platy foliation and the banding.

In the southeastern Baltimore gneiss area the linear elements parallel that of the adjacent gabbro complex. In the northeast Baltimore gneiss area, where a fault intervenes between the gabbro and the gneiss area, the linear elements are at right angles. The linear foliation in the Wissahickon schist areas of the complex south of Bare Hills is parallel to that in the amphibolites.

JOINTS AND DIKES

The only significant joint system of the gabbroic rocks is a set roughly perpedicular to the linear foliation (Plate XL, Fig. 2). It is best developed in the exposures along the Patapsco River both south of Hollofield and on Bull Branch near Glenartney. It is confined almost entirely to amphibolites of the gabbro complex.

In the vicinity of Orange Grove most of the pegmatite dikes dip about 20 degrees east, which is roughly perpendicular to the very steep linear foliation.

INTERPRETATION OF THE STRUCTURE

Except for discussions in the section dealing with petrography of the rocks, the foregoing pages have been devoted to a presentation of observations. In the following section the significance of the directed structures will be discussed. Attention is focused on the metamorphic structure. An attempt will be made to show first that the cleavage is of metamorphic origin. Second, the significance of the orientation of planar and linear schistosity will then be discussed independently and the character of the deformation will be deduced forthwith.

METAMORPHIC ORIGIN OF THE AMPHIBOLITES

The most remarkable structural feature is the conformity of the amphibolite foliation with the boundary of the gabbro mass. Such conformity of foliation in an igneous mass has generally been regarded as evidence of the primary origin of that foliation. In the present instance, however, this foliation is believed to be secondary. The following facts attest to its metamorphic origin:

1. In terrains which have not been dynamically metamorphosed subsequent to intrusion, intrusives are unknown as amphibolite but are rather gabbros and diabases and related pyrogenic rocks. Further, primary foliation is known to accompany the typical pyrogenic facies, as for example, in the brown hornblende-bearing gabbro and the Peekskill norite (8).

2. The texture of the amphibolites is crystalloblastic (Page 219).

3. Primary banding and a later cleavage are not always mutually parallel. Though rarely, they differ in strike and dip and the cleavage as a rule is steeper than the banding. Exposures have been found in which the cleavage transects the bands.

4. The author believes that the relation between primary banding and secondary cleavage in the gabbro complex is paralleled by a similar relationship between primary and secondary structures in the adjacent wall rocks. Within the gabbro complex banding is a highly irregular structure; being bent, folded, flexed, generally with a great freedom of orientation. The direction of cleavage, on the other hand, is much more persistent over larger areas. Irregularities in the banding are furthermore transgressed by cleavage. This is comparable with the highly irregular orientation of folded bedding or of folded gneissic bands. Cleavage clearly transects bedding and gneissic foliation and maintains a much more consistent orientation over a large area. Banding in gabbro and bedding or gneissic foliation seem therefore comparable primary structures, all of which are transected by a later and much more consistent cleavage.

The above comparison is not meant to imply that banding and bedding are of similar origin or that they have been formed at the same time. They are merely both primary structures transected by similar later ones. In addition, these later structures are parallel inside and outside of the gabbro complex and it seems therefore suggestive of a similar origin, and they may even have been formed at the same time.

5. It has been outlined above that primary and secondary structures within the gabbro complex are mostly conformable. In the sediments and gneisses of the adjacent wall rocks primary banding and bedding are also predominantly conformable because of intense folding. Since this folding is isoclinal the schistosity parallels the primary structures more often than

it transgresses it. Transgressions are rarely exposed but have been observed, clearly indicating that the schistosity is later than bedding or gneissic banding. Since banding in the gabbro is also folded, it seems very probable that this conformity can be explained in a similar way and it does not necessarily mean that the schistosity is a primary structure.

INTERPRETATION OF PLANAR SCHISTOSITY

The orientation of planar schistosity parallel with primary structures is highly significant. In the gabbro complex schistosity mostly parallels both primary banding and the contacts of the complex. In the country rocks it frequently parallels bedding, gneissic banding, formational boundaries, and the contact between the Baltimore gneiss and the Glenarm series. The area in which this relation prevails is considerably larger than the gabbro complex and includes in Maryland the entire area in which Baltimore gneiss occurs, a strip at least 20 miles wide and 80 miles long in a northeast-southwest direction (see Parts II, III, and IV of this volume). The dynamic conditions in this area seem to be, as the grade of metamorphism and the uniformity of structures indicate, an accentuated form of the conditions governing Appalachian deformation. Between the open folds of the western Appalachians and the strip of crystalline schists containing the gabbro and basement gneiss is a belt of slates, phyllites, and other low-grade metamorphosed rocks in which the folds are isoclinal and the limbs are nearly parallel to one another and to a flow cleavage. Intensity of folding, it may therefore be inferred, has aligned bedding and flow cleavage planes with banding and schistosity in the highly crystalline rocks. Folding of such intensity is best described as flow and the planes of greatest dilation, which are planes of alignment, may be termed flow planes (flow cleavage). The planes of schistosity in the gabbro complex, as well as in the country rocks, are thus interpreted as flow planes.

INTERPRETATION OF LINEAR SCHISTOSITY

Linear schistosity (stretching in sediments or flow lines in igneous rocks) are coupled with cross joints (see Pt. I of this volume). The joints may therefore frequently furnish the clue to the interpretation of such linear structures. The cross joints in the amphibolites are closely related to the linear structure and of the same nature as those described in the Setters quartzite, the Port Deposit granite, and many other localities (see Page 74 of this volume). They could conceivably be a response to thermal dilation, the orientation of the most elongated fibre having been determined by the aeolotropic character of the amphibolite rock. However, such thermal strains are small in comparison with the dynamic con-

ditions which induced flow and schistosity. Linear schistosity and the greatest elongation during deformation are both perpendicular to the cross joints and therefore parallel.

ORIGIN OF SECONDARY STRUCTURES

The author believes that the secondary structures in the gabbro complex have been superimposed on primary flow structures during a period of general regional metamorphism of the crystalline rocks of the Piedmont Province.

The alignments are due to unequal yielding of different rock masses to the deforming forces. Thus tongues or sheets flowed at different rates and past each other. Primary structures may have been rotated until they became parallel to the secondary ones, comparable to the rotation of bedding planes into subparallel positions, and the formation of a cleavage parallel to these bedding planes.

The parallelism of primary and secondary structures in the Baltimore gabbro and the surrounding rocks is interpreted to indicate a strong secondary flow motion with intense shearing between the different portions of the rock masses.

The basin-like arrangement of the cleavages and the convergence of linear schistosity towards a central area is believed to be due to an adaption of the gabbro mass to the available space. Large, very resistant domes of Baltimore gneiss surround the gabbro on all sides. If these domes were being moved toward each other, for instance by lateral compression of the entire area, the gabbro and its parts would be squeezed upward and outward. The lines of greatest elongation—as shown in the linear schistosity—would then point the way of easiest escape.

The contact of the gabbro mass dips inward on three sides towards a central opening. From here the gabbro may have entered its present chamber between the gneiss domes. The shape of the primary intrusive was determined by the shape of the space of its chamber. Later orogeny has then most likely modified the shape somewhat and has tended to squeeze the gabbro upward. Lateral squeezing is indicated by the overturned folds in the Baltimore gneiss to the southeast (Part III) and toward the gabbro mass. During this period of deformation the secondary structures may have been produced.

Primary structures indicate that the gabbro has been a conformable intrusion into a synclinal area of the Glenarm series. It may be called a synclinal pluton (33). Its shape may be that of a sill or basin-like body, narrowing downward from the south, east, and north sides—wherever the Baltimore gneiss domes are nearest. At its west side the contact against

the Wissahickon schist is vertical and in part the gabbro has been intruded by a later granite (Ellicott City granite). All later deformation could only serve to modify its primary outlines slightly and to produce secondary structures which now predominate and have to a large extent obliterated the earlier ones. The secondary structures clearly indicate the directions in which the gabbro masses flowed during their metamorphism; that is, during the latest period in which it participated passively in the deformation of the crystalline rocks of the Piedmont area.

Editor's Note: The author's original manuscript has been edited to conform more closely with the later results of Broedel and Hershey in the adjacent regions.

The Baltimore Gneiss Domes and the Setters formation show abundant structures which are not parallel to those in the gabbro area (see Plates XLI, XXIX-XXXI). The planar schistosity of the gabbro and wall rocks are as a rule conformable, but locally the gabbro clearly cuts across them. The linear structures however are unconformable. This is shown on the west and north side of the gabbro complex and it is evident that the gabbro intrusion has invaded already schistose Glenarm sediments. This has been outlined by Hershey and Marshall (Pts. II and IV). Not all the structures within the gabbro and outside of the gabbro are due to *one* act of deformation.

The Editor believes that metamorphism and deformation subsequent to the gabbro intrusion followed local directions and probably old, preexisting lines, and not a general regional direction. The linear structures of the gabbro point inward from the northeast, east, and south sides which cannot be due to regional metamorphism alone. Schistosity does not transect the gabbro contact. This should also occur if a circular body is subjected to a regional deformation, accompanied by complete recrystallization.

In spite of the fact that a large portion of the gabbro structures has the appearance of secondary structures, all structures are locally related to the shape of the gabbro mass and in no way to a general regional direction.

It seems therefore most likely that the gabbro mass was deformed during a late stage of its intrusion, thus becoming a "primary gneiss," or during a later phase. If the gabbro structures are secondary, as discussed by the author, they may have been formed during a period which affected the entire Piedmont Province, but in close adherence to local conditions, as is indicated in the arrangements of structures seen on Plate XLI.

For these reasons the editor has changed Mr. Cohen's conclusions somewhat, however, without the author's permission, who could not be reached on time. The editor is certain that the author would have modified his conclusions if the newer material had been available to him. The major portion of the paper is in no way affected by the newer findings or the conclusions derived from them.

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FIG. 1.—Foliation cutting bands in the Baltimore gneiss. South bluff of Lake Roland.

FIG. 2.—Feathery serpentine, natural scale. One mile north of Union Dam.

FIG. 1A.—Specimen of chloritized amphibolite. Patapsco River southeast of Hollofield.

FIG. 1B.—Honeycomb ironstone with residual serpentine. Cedar Branch. Natural size.

FIG. 2.—Gabbro pegmatite north of Union Dam.

FIG. 1.—Thin acid bands in amphibolite. Patapsco River one mile southeast of Hollofield.

FIG. 2.—Joints refracted by banding. Baltimore and Ohio Railroad, south of Hollofield.

FIG. 1. Banded ultrabasics. Northeast of Western Maryland Railroad and Gwynns Falls Parkway.

FIG. 2. Schistose zone in gabbro. Western Maryland Railroad at Sudbrook Park.

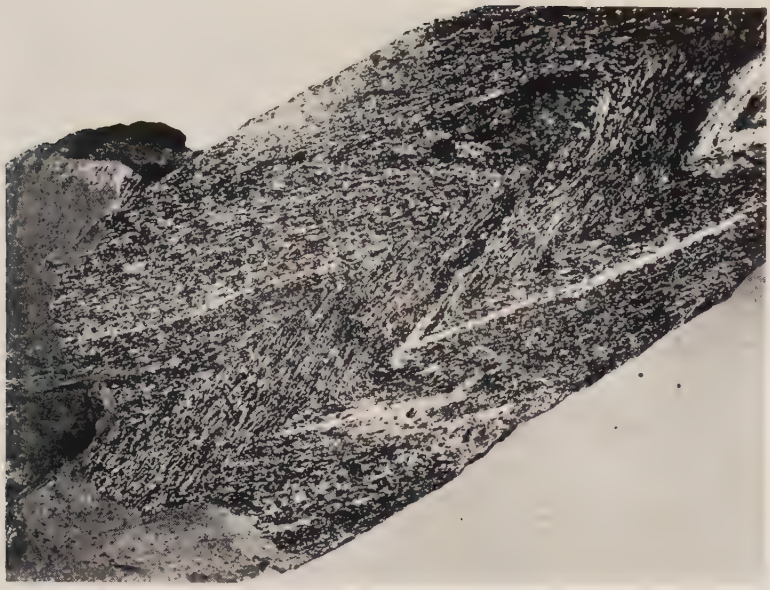

FIG. 1.—Sharply folded linear foliation of amphibolite. Specimen from south of Union Dam, Baltimore County. Natural size.

FIG. 2.—Cross jointing. Patapsco River, one mile southeast of Hollofield.

VITA

Charles J. Cohen was born in Baltimore, Maryland, on August 21, 1911. His elementary and high school education was obtained in the public schools. He entered the Arts and Science School of the Johns Hopkins University in October 1927, transferred to the Engineering School in the fall of 1928, and completed the third year course in Civil Engineering in the spring of 1930. He entered the Geology Department under the Goodnow plan in the fall of 1930 and has studied in that department since then. The Bachelor of Arts degree from the University was granted him in 1931.